# FIRE MANAGEMENT IN A CHANGING LANDSCAPE: A CASE STUDY FROM LOPÉ NATIONAL PARK, GABON

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## ABSTRACT

A key management goal in Lopé National Park, Gabon, is to protect regionally-rare savannah ecosystems within the continuous rainforest block. In order to evaluate the impact of existing protection efforts, data on burning season environmental conditions, burning effort and current woody values for savannahs were examined between 1995 and 2008. Results showed (a) spatial heterogeneity in woody values to be correlated with grassy vegetation type (b) a negative relationship between woody vegetation and fire return frequency over the study, suggesting that decreased fire return frequency may favour savannah thickening and (c) that inconsistent burn effort by Park staff, and burns designed for reduced heat, may limit the efficiency of fire to prevent savannah thickening or forest expansion. Optimal humidity and fuel moisture conditions for burning are identified and recommendations made for improving the existing fire plan to achieve the management goal. Modifications will require significant investment of resources and training and require urgent experimental work to disentangle the direct impacts of fire from other processes of vegetation change. Lopé's fire policy should ultimately be a dynamic response to change in the local landscape driven by direct fire impacts or by global climate change.

**KEYWORDS**: fire management, savannah ecosystems, Lopé National Park, Gabon,

## INTRODUCTION

Both forest expansion and savannah thickening (an increase in density of savannah woody species) are significant challenges for the long-term management of protected savannahs in Africa, yet have received limited attention from the research or conservation communities and park managers have limited knowledge or critical assessment of practical management tools for savannah preservation. Forest expansion into savannah habitats, in response to global and local drivers, is common in Southern Africa (Parr et al., 2012; Wigley et al., 2010), West Africa (Goetze et al., 2006; Fairhead & Leach, 1996; Wardell et al., 2003), Eastern Africa (Leuthold, 1996; Gil-Romera et al., 2011; Belsky & Amundson, 1992) and is increasingly reported for Central Africa (Maley, 1990; Dowsett & Dowsett-Lemaire, 1991; Schwartz et al., 1996; Vincens et al., 2000; Guillet et al., 2001; Mitchard et al., 2009). In addition to forest expansion, savannah thickening is also occurring as a parallel process within savannahs, particularly in southern Africa (Parr et al., 2012). Recent studies suggest that Gabon's savannahs, which cover an estimated 20 per cent of the country, are being encroached by forest (Delegue et al., 2001; Nana, 2005; Leal et al., 2007). Some coastal forests in Gabon and the Republic of Congo are the result of expansion occurring in the past 500 – 1000 years (Delegue et al., 2001), with a rate as high as 50 m per century (Schwartz et al., 1996). Encroachment occurs from both the continuous forest edge and as islands of forest species that become established in the savannah (Favier et al., 2004). In these savannahs, fire slows forest progression but does not stop it (de Foresta, 1990) and protection of the forest edge has been found to favour forest expansion (King et al., 1997). Fire-resistant forest-edge species protect forests from fires (Koechlin, 1961, Dowsett-Lemaire, 1996) and facilitate forest expansion. In Central Africa, savannah thickening is rarely reported, but in Gabon, one study suggests that this process is also occurring, due to changes in traditional fire regimes (Walters, 2012).

Forest expansion and savannah thickening were not considered a conservation issue in Central Africa until recently, as forest conservation has been the overall priority for the region. However, the savannah ecosystems are regionally rare and can form important islands of habitat, harbouring nationally rare savannah specialist species and providing significant patches of preferred habitat for species such as forest buffalo, forest elephant and bushbuck, which can reach locally high densities (Vande Weghe, 2011; Walters et al., 2012). This is the case for Lopé National Park which protects savannahs of the middle Ogooué region in central Gabon. Understanding savannah ecosystem change, its potential interaction with climate change and the role of direct management intervention is therefore particularly relevant to the case of Lopé National Park, where management objectives aim to maintain these important habitats.

In Gabon, 13 out of 20 state-managed strict protected areas harbour some savannah. Although anthropogenic savannah fires are commonplace, Lopé National Park (a UNESCO World Heritage site), is one of only two protected areas in Gabon to use a prescriptive fire programme to manage its savannahs, which it has done since 1993. Fire has been used by humans in Gabon for thousands of years, and Lopé's savannahs are thought to be relicts of a dynamic vegetation history linked to historic human migration events and past climatic conditions (Maley, 2001; Oslisly, 2001; White, 2001; Ngomanda et al., 2007). Human fire activity combined with a dry climate is thought to have maintained large areas of savannah between 2000–3000 years ago (Oslisly & Peyrot, 1992; Peyrot et al., 2003; White, 1995). A period of human absence beginning around 1400 BP coincided with more humid conditions and rapid forest expansion (Oslisly, 1995; Oslisly, 2001; White, 1995; White, 2001), indicating that both historical human activities and climate have contributed to alternating trends in forest/savannah conversion. Lopé's forests have been expanding for the past 2,500 years (Palla et al., 2011) and islands of forest vegetation are also being established within the savannahs (White, 1995; Ukizintambara et al., 2007).

The Lopé fire management programme was originally implemented with the objectives of reducing rates of forest expansion into the savannah, maintaining the diversity of habitats at the forest/savannah transition zone and encouraging seasonal use of the savannahs by large mammals to improve tourism opportunities (White, 1995; Molloy, 1997; Ukizintambara et al., 2007). Despite the annual fires, forest expansion is occurring rapidly (Nana, 2005; Palla et al., 2011) and visible changes in savannah structure can be seen. Some unburned areas at forest edges have made a clear transformation from savannah to colonising forest in just 15 years (see photo 1).

As savannah conservation has traditionally been a lower priority than wildlife or forest conservation, the managed burning plan has been implemented with limited resources and a lack of trained personnel. Until now there has been no empirical evaluation of the effectiveness of the burn plan to achieve its management objectives. In the context of climate change, understanding the most balanced management response to a landscape changed by both global and local drivers is becoming more critical, as Lopé strives to protect its unique ecosystems for the long term.

In this paper we examine data from the fire management programme in Lopé to investigate the results of the current burning practices. We address the following questions:

1. Is there an underlying influence of savannah grass type on the distribution of woody vegetation in Lopé savannahs?
2. Is there a relationship between the fire return frequency and the woody vegetation cover within the managed savannah zone?
3. Is burn effort consistent throughout the fire season and efficient for the management goals?
4. When are the optimal conditions during the day and during the season for burning?

## MATERIALS AND METHODS

Fire Management Programme*:* The study area comprises a mosaic of savannah units in the north of Lopé National Park covering a total of 3,940 hectares (Figure 1). Two main types of savannah vegetation have been described according to their grass species composition, and their distribution is determined mainly by erosion and soil

**Photo 1: Forest encroachment of a single savannah patch in Lopé National Park, which has not burned since at least 1993. Top photo: in 1993, the patch is a densely shrubbed savannah readily distinguished from the adjacent forest block. Bottom photo: in 2008, the same patch has transformed into colonising forest and the forest-savannah boundary has shifted >100m © Lee JT White and Fiona Maisels**

moisture content (Alers & Blom, 1988). Type 1 savannah, found mostly in the north of the study area, is species poor, dominated by *Anadelphia afzeliana*. Type 2 savannah, typical of the southern savannahs, is species rich, dominated by *Hyparrhenia diplandra*, *Schizachyrium platyphyllum* and *Panicum nervatum* (Alers & Blom, 1988). Both types contain woody shrubs, principally of the species *Sarcocephalus latifolius, Crossopteryx febrifuga and Psidium guineense* (White, 1995).

In 1993 a fire management programme was developed, consisting of an annual burn scheme with most areas programmed for annual burns. A 790 hectare area, including both Type 1 and Type 2 savannahs, was set aside for either a 2–3 year fire return period, or protected entirely from burning (Figure 1), in order to maintain habitat diversity at the savannah/forest transition zone and preserve savannah patches of guava (*Psidium guineensis*) which draw elephants into open areas for tourist viewing. Savannah units (determined in size by firebreaks) were burned progressively over a six-week burn season between July and September, to extend seasonal visibility of buffalo by staggering sward regrowth. Actual inter-annual start and stop dates vary slightly according to seasonal rainfall, but planned burns started in late July when grasses were sufficiently dry for combustion. From 1993–2001 around 20 large savannah

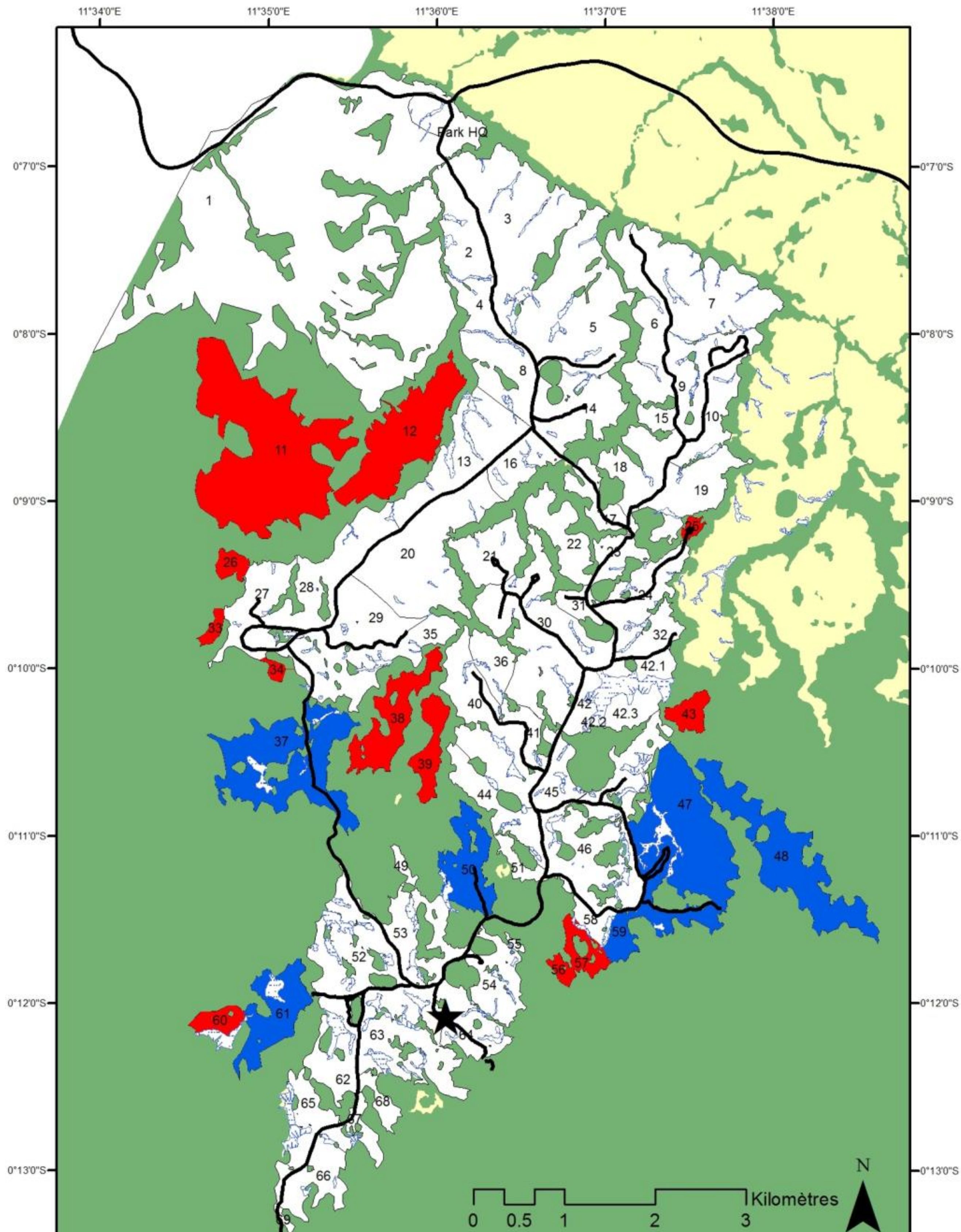


**Figure 1: Map of the study area and managed burn zone, Lopé National Park, Gabon. White numbered zones are savannahs programmed for annual burns, red are savannahs protected from fire, and blue are savannahs on a 2-3 year burn cycle. Forested habitat is green and yellow areas are savannahs outside the managed burn zone. Thick black lines indicate roads, thin black lines indicate locations of fire breaks that separate savannah units. Marshes are outlined in blue. The star indicates the location of rainfall and humidity data collection.**

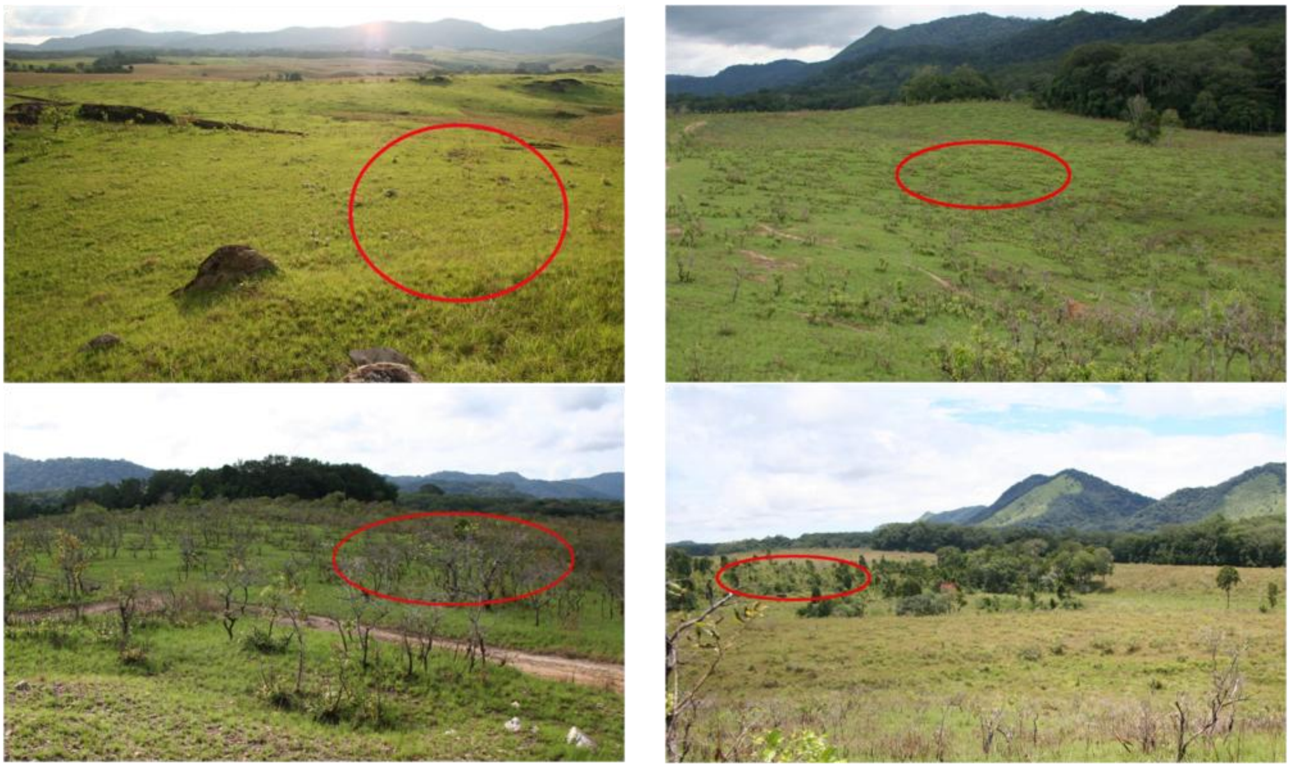

**Figure 2: Four vegetation types identified in Lopé's savannahs in October 2008 from photographic interpretation (as identified inside the red ellipses). Top left: open savannah; Top right: young woody savannah; Bottom left: mature woody savannah; Bottom right: colonising forest © Kathryn J Jeffery**

units were defined by natural firebreaks such as roads, marshes and forests, thus these units were not necessarily related to their biological characteristics or animal use. In 2002, the savannah units were revised to better incorporate knowledge of buffalo home ranges (Molloy, 1997; Korte, 2008) and 69 smaller distinct savannah units were identified, separated by natural firebreaks and man-made barriers cut with machetes one month prior to the burn season. Fires were lit between 15:00 and 18:00 as a security measure to favour less intense, more controllable fires. Burn dates and savannah units burned were recorded and data were managed in an ArcGIS 9.x database (ESRI), which was also used to calculate the original areas of each savannah unit. Burn areas were not directly measured but estimated as the whole area of the savannah unit that had been lit on a particular date. During some years, environmental conditions led to incomplete burns of some units; these incompletely burned savannahs were either re-burned at a later date if less than approximately half of the unit had originally burned, or left partially burned if the majority of the unit had been burned. Partial burn areas were recorded on maps wherever possible. Annual burn plans were prepared and implemented each year, although data on burn dates and spatial accuracy of implementation of the burn plan for each savannah unit were incomplete for some years. We considered data collected during a 14 year period between 1995 and 2008, where complete data were available for nine years. No data existed for 1993 and 1994, which were not considered in this study. Only these years are used for analysis of the burn effort. Human error and environmental conditions did lead to some error in spatial implementation of the burning plan, however recorded fire return frequencies were close to the burn plan prediction (see Figure 3 in results section).

**Vegetation Classification**: In Central Africa, and elsewhere, definitions of savannah types based on tree density have been proposed (Conseil Scientifique pour l'Afrique, 1956; UNESCO, 1973) but never universally adopted (Bourlière & Hadley, 1983), leaving researchers and managers to adopt measures adapted to their situation. In this study, the following method was used to create a local objective standard, against which change can be measured. The equivalence of our four classes to the terms used in other Lopé literature (White, 1995; White, 2001) is indicated for each one, to avoid confusion and create a single standard terminology.

Digital photographic images were taken from each ordinal and cardinal direction at 29 viewpoints across the study area in October 2008 using a Canon 3EOS 350D at ISO 200-400, and GPS locations were recorded. Over 150 point locations were randomly selected from the photographs and visually inspected. The area immediately surrounding each point (between 10 and 50 m radius) was assigned to one of four vegetation categories from visual inspection of images (Figure 2), along with corresponding four point 'woody vegetation' score as follows: (1) Open savannah: woody shrubs rare or absent (n=40): White (2001) "Savannah vegetation"; (2) Young woody savannah: woody shrubs common, young woody shrubs <1 m in height dominate (n=26): White (2001) "Savannah vegetation"; (3) Mature woody savannah: woody shrubs common, mature woody shrubs >1 m in height dominate (n=45): White (2001) "Savannah vegetation"; (4) Expanding forest: savannah species rare or absent, colonising tree species dominant (n=12): White (2001) "Colonising Forest". Point locations were rejected if they did not fall into one of the four vegetation categories described above (e.g. mature forest block or marsh). In cases where the point fell on mixed vegetation types, the prevailing vegetation type visible in the photograph was used to assign the vegetation category. In total 123 point locations were retained, representing 52 different savannah units inside the managed burn zone.

**Environmental data**: Four seasons are recognized at Lopé: a short dry season occurring between December and February, a long dry season (mid June to mid September) and two rainy seasons (Vande Weghe, 2011). We defined the "average" long dry season from rainfall data which were collected daily in Lopé from a single savannah location at the *Station d'Etudes des Gorilles et Chimpanzés* (Figure 1) between 1984 and 2009: average annual rainfall is 1483 mm (SD 191). Weeks where average rainfall was below 20 mm were considered "dry season"; these corresponded to a 14 week period between 11 June and 16 September. Early season was defined as the period 11 June–15 July; mid season 16 July–19 August; and late season 20 August–16 September. Humidity data were collected at the same savannah location every 15 minutes between 2002 and 2008 using automated data loggers (HOBO data logger 2002–2006; TinyTag Plus 2007–2008).

## RESULTS

1. **Influence of grass savannah type on current woody vegetation:** To control for the effects of fire treatment, we restricted this analysis only to savannahs that had been burned annually. Mean woody vegetation scores for annually burned Type 1 and Type 2 savannahs (Alers & Blom, 1988) were 2.18 (SD 0.96) and 1.71 (SD 0.83) respectively (n= 92), a difference that was significant (Mann Whitney U test, W = 1668; p = 0.018, adjusted for ties).

2. **Relationship between fire return frequency and woody vegetation cover:** We plotted average woody vegetation scores as a function of the planned fire return frequencies; i.e. savannahs that were planned to burn annually, on a 2-3 year rotation, or never burned (Figure 3) and tested for differences in 2008 woody vegetation scores between fire return categories for each savannah type. Sample sizes were too small to permit an analysis of Type 2 savannahs, however within Type 1 savannahs our results suggest a negative relationship between woody vegetation and planned fire return frequency. Mann-Whitney U tests between paired categories confirmed a significant difference between Never Burned and Burned Annually (W=1334, p < 0.01, adjusted for ties), and between Never Burned and Burned Every 2 - 3 years (W=179, p = 0.02, adjusted for ties), but not between Burned Annually and Burned Every 2 - 3 years (W = 1591, p = 0.092, adjusted for ties).

   By assuming that for years in which burn data were not recorded for a given savannah a value of either 0 (unburned) or 1 (burned) could be true, we then calculated the maximum and minimum possible fire return frequencies for all savannahs over the 14 year period. We compared savannahs that fell into one of two discrete groups; those that had burned the least often (between 0 and 7 times) and those that had burned the most often (between 8 and 14 times). The analysis was restricted to Savannah Type 1 due to inadequate sample sizes for Type 2 savannahs. Although sample sizes were small for Type 1, median woody vegetation scores were significantly higher for savannahs burned 0-7 times than those burned 8-14 times (0 – 7 times, Mean = 3.37, SD 0.54, n = 7; 8 - 14 times, Mean = 2.00, SD 0.90, n = 43; ,Mann Whitney U test, W= 972, p < 0.01, adjusted for ties).

3. **Consistency of burn effort throughout the fire season:** The fire plan is designed to evenly allocate burn dates across the six-week burn season, however, logistical constraints, errors made by burn operators and accidental fires resulted in actual burn dates frequently differing from those planned.

   Very few fires (2 per cent) were recorded early in the dry season. The majority of all fires (87 per cent) were recorded between 30 July and 16 September, with large variations observed across weeks (Figure 4). No significant difference was found between the frequency of mid and late dry season fires ($\chi^2$ (1) = 3.39, N = 382, NS); 40 per cent of all recorded fires were mid dry season and 48 per cent were late dry season. The remainder were either out of season or no date was recorded. The week of the 6 August had the highest number of fires recorded, and with the exception of the week of 13 August, subsequent weeks

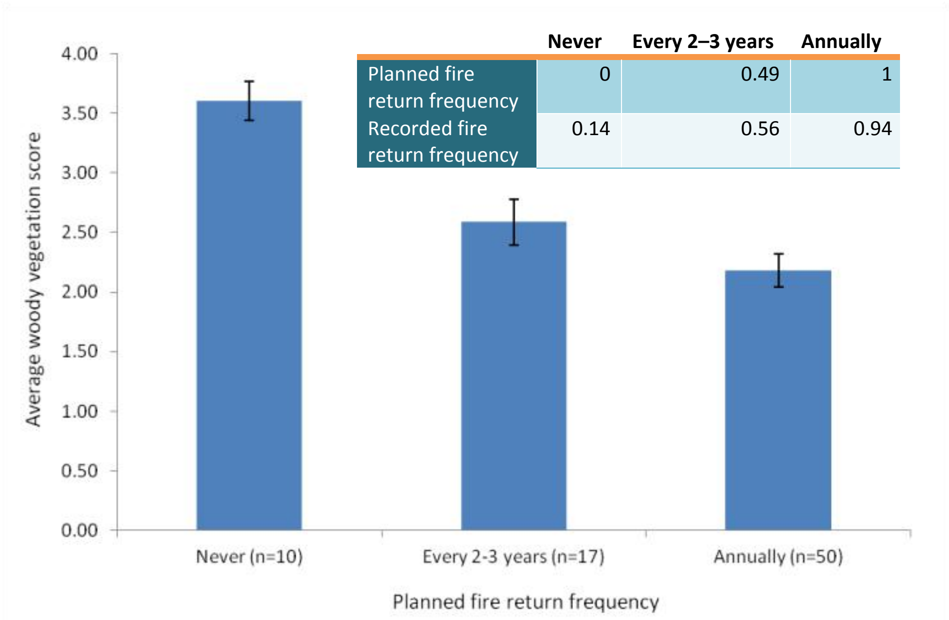


**Figure 3: Average woody vegetation scores (+/– 1 SE) in 2008 for 77 locations in savannah grass Type 1 in Lopé National Park, plotted as a function of planned fire return frequencies over 14 years. Recorded fire return frequencies for the same savannah locations are calculated as averages over years where there are available data**

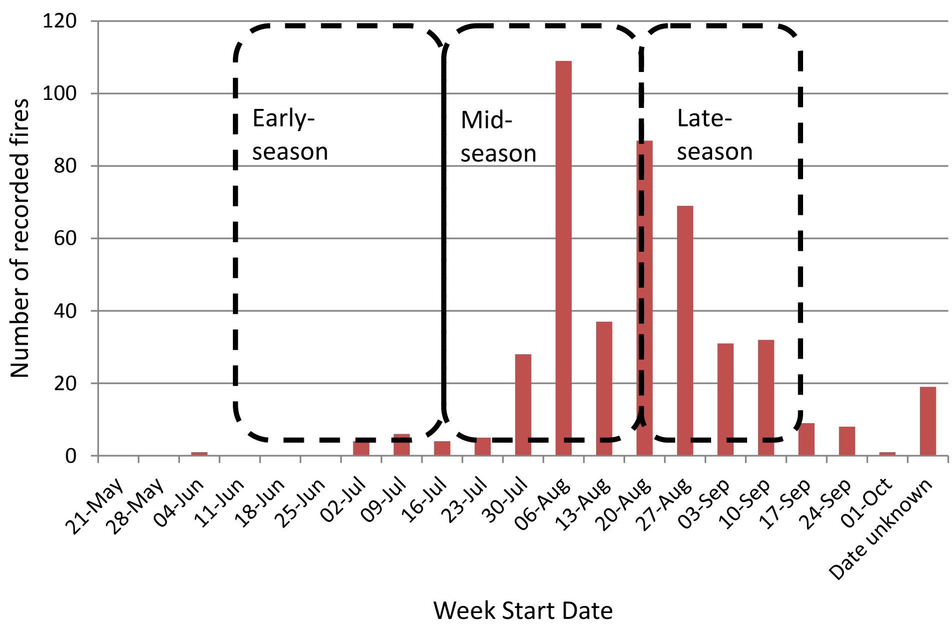


**Figure 4: Frequency distribution of recorded fire dates across the long dry season (11th June- 16th Sept) in Lopé National Park, from available data between 1995 and 2008**

showed a progressively diminishing number of burns, with a strong negative correlation between burn week and the number of recorded fires from the 6 August onwards ($r_s$ = -0.933, N = 9, p < 0.001). The 13–19 August dip coincides with the mid August national holidays, and is indicative of a lack of available human resources during this week.

4. **Optimal humidity conditions for burning***:* Average hourly relative humidity values plotted throughout the day in Lopé savannahs show that they are at their lowest between 11:30 and 14:30 daily, when minimum average values of 60 per cent are observed (range 31–100 per cent; Figure 5a). However, burning was deliberately executed between 15:00–18:00, when average humidity levels are between 63–83 per cent (range 35–100 per cent). Average weekly humidity levels plotted throughout the dry season (Figure 5b) show that while variations in humidity are large for any one week, a general trend of decreasing humidity is observed as the dry season progresses. Humidity is lowest in the late dry season, with the recommended optimal burn period identified between 20 August and 16 September. This part of the late dry season is also when dry matter in grass swards is high and fuel moisture likely to be lowest (Molloy, 1997).

## DISCUSSION

The results presented here show a negative relationship between fire return and savannah thickness within savannahs of the same grass type. However, additional photographic evidence suggests that the Lopé forest/savannah boundary is also changing, allowing forest expansion (Nana, 2005) and that savannahs newly protected from fire by forest-edge changes can thicken

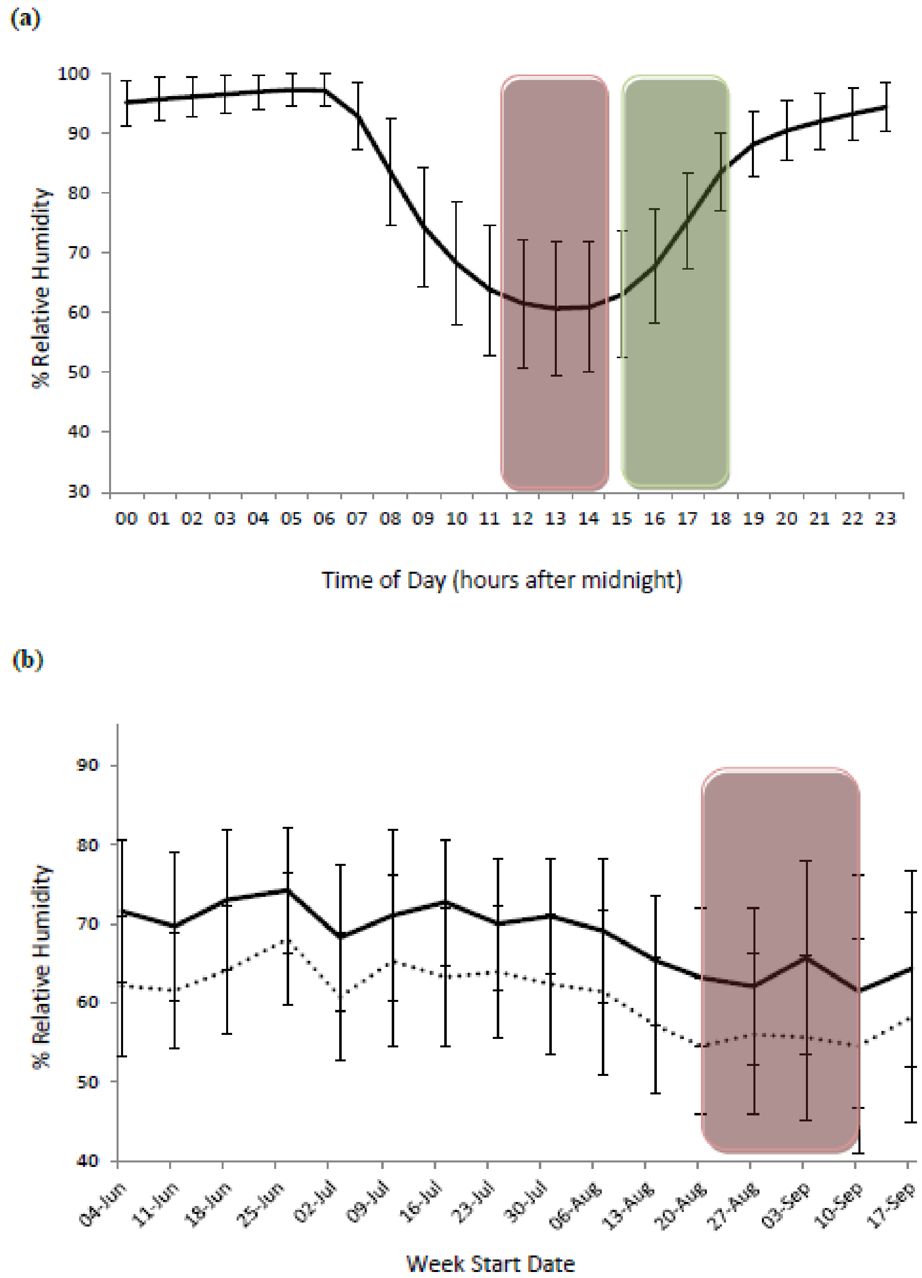


**Figure 5: Plots of humidity throughout the long dry season (11th June --- 16th September) in Lopé National Park, 2002-2008. (a) average hourly relative humidity (%) values (+/– 1 SD). Green = current burn time; red = optimal burn time. (b) average relative humidity levels (+/- 1 SD) throughout the dry season (+/- 1 week) for the implemented burn time (15:00-18:00; solid line) and the optimal burn time (11.30-14:30; dotted line). Red = optimal burn dates**

sufficiently over a 15 year period to be classed as colonising forest (see Photo 1). Our data demonstrate that whilst fire appears to be having a significant effect on Lopé savannah vegetation, the efficiency of current fire use as a tool to preserve Lopé's savannah habitats is hard to evaluate.

**Savannah grass types***:* The significant effect of savannah grass type on savannah thickness shown by our analyses was not taken into account in the original burning plan. Thus the distribution and number of savannah burn units are not stratified across savannah grass types, making statistical interpretation of results problematic. Our experience indicates that the burn plan should be further developed to include explicit monitoring that will permit better analysis of the effect of fire return on savannahs with different grass types, and examine potential differences in fuel loads between savannah grass types.

**Fire intensity**: The data show that inconsistent burn effort within burn seasons and bias to burning conducted at times of both relatively high daily humidity and high seasonal fuel moisture conditions, are likely to have reduced the intensity of fires.

Our assessment of the environmental conditions during the burning season indicates that there is potential to increase fire intensity and possibly increase the impacts of fire on the observed savannah thickening and forest expansion seen at Lopé. We identify ways in which the existing fire plan, burning practice and environmental

A low intensity fire, Lopé National Park, Gabon © Nicolas Rumboll

monitoring in the park might be improved to make fire a more effective tool for savannah preservation in Lopé and increase managers' ability to evaluate its impacts.

Fire intensity is influenced by fuel moisture, air temperature and wind speed (Trollope et al., 2004), yet the burning plan in Lopé has promoted burns in sub-optimal humidity conditions and not used data on fuel loads, wind or air temperature to inform daily burning practices. Whilst high humidity burn times were chosen as a security measure, they have probably also contributed to a less efficient burn, lower impact against savannah thickening and forest expansion, and ultimately undermined progress toward the management goal.

Although our findings indicate a correlation between past fire frequency and current woody vegetation, data on fire intensity or speed are lacking and thus the effect of increasing fire intensity (heat, completeness of combustion) in these savannahs types cannot be accurately evaluated.

It is likely that favouring more intense fires, by targeting the least humid parts of the day (11:30–14:30) and season (20 August–10 September), and times of lowest fuel moisture would better inhibit savannah thickening and forest expansion. Collection of environmental data on wind speed, wind direction, temperature and measurement of resulting fire heat and speed throughout the burn season, would contribute greatly to more accurate identification of optimal burn conditions enabling adjustment of the weekly burn plan specific to each season (Higgins et al., 2000; Govender et al., 2006). Since 2010, data on wind speed and wind direction have been incorporated into the routine burn data collection protocols in the Park, and future analyses should allow further refinement of optimal burn times.

**Fire return period***:* Our data show an effect of fire on savannah woody vegetation in Lopé, with protected savannahs having significantly higher woody values than those regularly burned. However, although woody values are the lowest for annually burned savannahs, our data do not yet suggest that annual burns are significantly more effective at reducing savannah thickening than a 2-3 year fire return period. Elsewhere, fire return period is known to be a critical parameter for maintaining savannah structure (Sankaran et al., 2005), In Gabon, two dry seasons have traditionally allowed twice yearly burns in some savannahs, although this practice was stopped in Lopé in 1993, due to concerns over impacts on nesting birds in the short dry season (White,1995). There is currently debate around the question of whether a twice yearly fire return period (i.e. burns in both the short and long dry seasons) would be more effective for

**Savannah fire at night, Lopé National Park, Gabon © David Greyo**

savannah management. It may be possible to obtain more intense fires by increasing the fire interval (Higgins et al., 2007); however variations of fire return over 1, 2, and 3 years elsewhere have shown to impact woody stem density both positively and negatively (Higgins et al., 2007) and evidence from elsewhere in Gabon suggests that woody stems may even increase with increased fire frequency (Walters, 2012). In a high rainfall savannah such as Lopé, it is possible that an early, short dry season burn will reduce fuel loads and therefore the intensity and efficacy of the ensuing late season burn (Higgins et al., 2000). A more detailed study of fire return periods and woody stem density in Lopé is recommended, together with assessment of other ecological factors, such as wildlife use of savannahs in the short dry season.

**Burn effort***:* The current burning plan demands fires evenly spread across the season from July-September, however, the within-season fire frequency has been heavily biased against mid season burns (at the onset of burning), and uneven across the remaining weeks. This is likely due to staff and logistic disruptions during the holiday week leading to subsequent alterations of the programme, combined with a decrease in motivation to burn as the season progresses.

As both improving fire intensity and reducing the management burden seem desirable, a shorter, later burning season should be implemented.

**Extent of fire management***:* Due to logistical constraints, the managed burn plan has been implemented in a restricted area; it is now a park management objective to extend this to cover all savannahs inside the park and its buffer zone (ANPN 2013). Many of these areas are already burned annually by the local community, but without planning, monitoring or involvement by the park authorities. In other countries, wildfire management programmes may be closely linked to local communities (Parr et al., 2009), particularly where fire management is cultural, resources are lacking and fires pose a threat to human safety and livelihoods (Laris, 2002; Myers, 2006). As is the case elsewhere in Gabon, unplanned savannah fires in Lopé can be started deliberately, either to facilitate hunting or to clear land amongst other uses (Walters, 2010), fire safety awareness is lacking and fire damage to infrastructures is often sustained. It is clearly in the park's strongest interests to involve the local community in fire management, not only to improve ecological and landscape level monitoring of fire behaviour and impacts, but also to facilitate park management efforts to control hunting and address local safety issues (Walters et al., in press).

The data on woody vegetation cover presented in this study are preliminary. More accurate measures of change are required, including quantitative measures of above ground biomass and stem density, which will allow pre- and post- treatment comparisons. Several studies have used large-scale methods to establish landscape level biomass: measures from forest plots in Lopé have already been used to quantify satellite imagery for estimating carbon stocks at a landscape level (Mitchard et al., 2011), and this approach could be extended to improve resolution for mapping above ground biomass

in savannah ecosystems. Although rarely used in Central Africa (e.g. Leuthold, 1996; Wigley et al., 2010), the fixed-point photomonitoring methods employed here also permit a simple method of identifying broad differences in vegetation structure over a large area that can be easily repeated to provide robust indicators of change.
Factors such as the surface area of savannahs, their proximity to adjacent continuous forest, and their potential humidity levels as well as those in the forest edge are important in fire regimes established to limit forest expansion. In Lopé these factors co-vary with savannah grass type, making a better understanding of the response of different grass types to fire particularly important for managers. If global climate-induced changes in the savannah/forest dynamic are occurring across Gabon, as seems likely to be the case, then more detailed studies examining how expansion processes are influenced by these factors are critical and urgent.

Unlike other savannah areas where fire management has long been practiced, such as those in South Africa, Australia, or the United States (Bradstock et al., 2002; du Toit et al., 2003; Pyne, 1988), in Gabon, savannah management is rare and poorly funded (Walters, 2010), a common limitation in sub-Saharan African protected areas (Goldammer & de Ronde, 2004). The state of fire management in Lopé highlights several factors more general to park management, in particular when managers are trying to address newly identified threats, for which local technical skills are currently insufficient. If global drivers are indeed responsible for Lopé's savannah thickening, then creative solutions to maintaining savannah habitat may be needed, possibly including manual interventions such as tree removal or more extreme fire management regimes (Parr et al., 2012). Training and investment will be required to implement the recommended modifications and improve fire management practices to meet management goals. Over the past millennia, Lopé's ecosystems have fluctuated according to the prevailing climatic conditions. Over the next century, changes in global temperature are predicted to reduce forest cover in Gabon (Zelazowski et al., 2011) and with it associated fire behaviour is also expected to change (Delire et al., 2008), a phenomenon that may happen globally (Stephens et al., 2013). Lopé's fire management policy will need to be adaptive to these changes, as the landscape continues to evolve.

## ACKNOWLEDGEMENTS

We thank the Wildlife Conservation Society, Gabon; the Centre International de Recherches Médicales de Franceville, Gabon; University of Stirling, UK; the Ministry of Water and Forests, Gabon and the EU DG VIII ECOFAC programme for financial and logistical support to this study, and the following people for their contribution in the field: Rostand Aba'a, Simon Angoué, Serge Corbet, Dave Daversa, Michel Fernandez, Philipp Henschel, Alphonse Mackanga Missandzou, Fiona Maisels, Anicet Megne, Augustin Mihindou, Vianet Mihindou, Ludovic Momont, Ruth Starkey, Caroline Tutin, Yntze van der Hoek and Liz White, and the Brigade de Faune de la Lopé.

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**RESUMEN**

Uno de los objetivos clave de gestión en el Parque Nacional de Lopé, Gabón, es la protección de ecosistemas de sabana raros dentro del bloque continuo de bosque lluvioso. Con el fin de evaluar el impacto de los actuales esfuerzos de protección, se examinaron los datos sobre la temporada de quemas, las condiciones ambientales, los esfuerzos relacionados con las quemas y los valores actuales de las plantas leñosas de las sabanas entre 1995 y 2008. Los resultados mostraron (a) que la heterogeneidad espacial de los valores de las plantas leñosas se correlaciona con el tipo de vegetación de hierba; (b) una relación negativa entre la vegetación leñosa y la frecuencia de incendios sucesivos en una zona específica, lo que sugiere que la disminución de la frecuencia de incendios sucesivos puede favorecer el engrosamiento de la sabana; y (c) que los esfuerzos inconsistentes de quema por parte del personal del Parque y las quemas diseñadas para reducir el calor, pueden limitar la eficacia de los incendios para prevenir el engrosamiento de la sabana o la expansión del bosque. Se identificaron las condiciones óptimas de humedad y humedad del combustible para la quema y se formularon recomendaciones para mejorar el plan de manejo de incendios para alcanzar el objetivo de gestión. Las modificaciones precisarán tanto de una inversión significativa de recursos y capacitación como de un trabajo experimental urgente para separar los impactos directos del fuego de otros procesos de cambio de la vegetación. La política de Lopé en materia de incendios debería ser, en última instancia, una respuesta dinámica a los cambios en el paisaje local movida por los impactos directos de los incendios o por el cambio climático global.

**RÉSUMÉ**

L’un des objectifs clé de gestion du Parc National de la Lopé au Gabon est de protéger ses rares écosystèmes de savane au sein de la barrière continue de forêt équatoriale. Afin d'évaluer l'impact des efforts actuels de protection, on a collecté sur la période 1995-2008 toute une série de données sur les feux de savane, les conditions environnementales, l’effet des incendies provoqués et la biomasse ligneuse des savanes. Les résultats ont montré que (a) l'hétérogénéité spatiale des valeurs ligneuses est en corrélation avec la végétation composée de graminées, (b) une relation négative existe entre la végétation ligneuse et la fréquence des incendies constatée, ce qui laisse supposer qu’une fréquence moindre dans la périodicité des incendies pourrait favoriser l’épaississement de la savane, et enfin que (c) le manque de programmation dans les incendies déclenchés par les personnels chargés de l’entretien du Parc et les incendies à chaleur contrôlée, pourrait limiter l’efficacité de cette méthode pour empêcher l’épaississement de la savane ou l’expansion de la forêt. Les conditions optimales d’humidité ambiante et d'humidité du combustible ont été établies et des recommandations faites pour améliorer le plan de feu existant en vue de réaliser les objectifs de gestion préétablis. Toute modification nécessitera d'importants investissements en ressources et en formation ainsi qu’un travail expérimental en vue de distinguer les effets directs du feu des autres processus de changement de la végétation. La politique de feu à Lopé devrait constituer au bout du compte une réponse dynamique aux changements dans le paysage local induits par les impacts directs du feu, ou plus globalement, par le changement climatique mondial.